DEVELOPMENT OF REGIONAL TRAVEL-TIME TABLES FOR DIFFERENT GEOTECTONIC PROVINCES OF NORTHERN EURASIA

Victor V. Kirichenko and Yury A. Kraev
Western Services Corporation
Under subcontract to
Science Applications International Corporation

Sponsored by The Defense Threat Reduction Agency
Arms Control Technology Division
Nuclear Treaties Branch

Contract No. DSWA01-98-C-0029

ABSTRACT

During the last two years, new regional travel-time tables for different provinces of Northern Eurasia were developed in the framework of the Seismoacoustic Research for CTBT Monitoring project. This project is being performed by SAIC and its subcontractors: the Western Services Corporation, the Geophysical Survey of the Russian Academy of Sciences (RAS) and Complex Seismological Expedition (CSE) of the Joint Institute of Physics of the Earth of the RAS. One of the main objectives of the project is to calibrate travel times for regional seismic waves travelling to the seismic stations of the Russian Academy of Sciences included in the Comprehensive Nuclear-Test-Ban Treaty International Monitoring System (IMS).

The development of regional travel-time tables is based on the published data of origin times and locations of nuclear explosions as calibration sources. The data are from peaceful nuclear explosions on the territory of the former Soviet Union as well as underground nuclear tests at the Semipalatinsk test site, Amchitka Island, and the French Test Site in the Sahara. Values of arrival times for major regional seismic phases (Pn/P, Pg, Sn/S and Lg) were measured, analyzed and collected from the stations of the Geophysical Survey and Complex Seismological Expedition.

The territory of Northern Eurasia was subdivided into 11 provinces based on the results of the analysis of Pn travel times as well recently published papers on seismic and tectonic regionalization of Northern Eurasia. At the 22nd Seismic Research Symposium we present newly developed travel-time tables for the following provinces: Central-East-European territory, Cenozoic Folded Regions (Balkan and Carpathian mountains, Crimea-Caucasus-Kopet-Dagh, Tyan Shan), Ural folded region, West-Siberian platform, Kazakh massif, Altai and Sayan mountains, Siberian platform, Baikal rift zone, North East territory and Chukot Peninsula. For all the developed travel-time tables, modeling errors were calculated and their comparison with the IASPEI-91 tables is presented. The newly developed regional travel-time tables differ substantially from the IASPEI-91 travel-time tables. For the Pn seismic phase at distances of 1,500 - 2,000 km, the deviations from the IASPEI-91 travel-time tables are as follows: -8 to -10 sec for the Central-East-European territory, West-Siberian and Siberian platforms; -4 to -5 sec for the Ural folded region, the Kazakh massif and the Baikal rift zone and -2 to +4 sec for the Cenozoic folded regions and Altai and Sayan mountains. For the Sn phase at the same distances, the deviations from the IASPEI-91 travel-time tables are, respectively: -15 to -20 sec, -8 to-10 sec and -5 to +5 sec. For the Pg phase, travelling in the Earth's crust, the deviations from the IASPEI-91 travel-time tables may be subdivided into two groups of provinces as follows: 1) platforms, Paleozoic massifs and Baikal rift zone and 2) Cenozoic folded regions and Altai and Sayan mountains. For the first group the deviations are from -3 to -5 sec at the distances of 700 - 1,000 km. For the second group travel times are consistent with the IASPEI-91 travel-time tables. Travel times for the Lg phase have large deviations even for geotectonically homogeneous provinces and are almost the same for the studied provinces. At the current stage of studies we accepted the value of 3.55 km/sec for the apparent velocity of Lg phase for all the studied provinces. In general, modeling errors for the newly developed travel-time tables are lower then those for the IASPEI-91 tables.

The newly developed travel-time tables as well as their modeling errors were used for tests on re-location of historical underground nuclear explosions at the territory of the former Soviet Union. We used seismic records of the stations included in the IMS or those stations, which are located not farther than 300 km from the IMS stations within geotectonically homogeneous regions. A comparison between the mislocation estimates for the newly developed travel-time tables and the IASPEI -91 travel-time tables is presented.

Key Words: Seismic Regional Characterization, Location Calibration.

OBJECTIVE

This work represents the results of a continued effort to develop regional travel-time tables for different geotectonic provinces of Northern Eurasia. The overall objective is to calibrate travel times for regional seismic waves travelling to the seismic stations of the Russian Academy of Sciences included in the Comprehensive Nuclear-Test-Ban Treaty International Monitoring System (IMS). The newly developed travel-time tables may be directly used to improve seismic event location as well as to test and to validate 3D travel-time models currently being developed.

RESEARCH ACCOMPLISHED

Regionalization

The regionalization of the territory of the Northern Eurasia was carried out on the basis of recent seismicity studies (Seismicity and Seismic Zoning of Northern Eurasia, 1993 and 1995), geological and tectonic features of deep structures (Deep Structure, 1991; Pavlenkova, 1996) as well as taking into account the results of our analysis of Pn travel times. For presentation of our results, the territory of the Northern Eurasia was subdivided into 11 provinces: Central-East-European territory, Cenozoic folded regions, Ural folded region, West-Siberian platform, Kazakh massif, Altai and Sayan region, Siberian platform, Baikal rift zone, Amur and Maritime territory, North East territory and Chukot Peninsula, Kamchatka-Kuril-Sakhalin region. The polygon vertices for the specific provinces are presented in Table 1. Figure 1 presents the regionalization of the territory of Northern Eurasia.

Calibration Events

It is obvious that underground nuclear explosions with announced data on time origins, locations and depths are the most appropriate calibration events. For the purposes of the IMS seismic calibration in Northern Eurasia underground nuclear explosions conducted at the territory of the former Soviet Union (peaceful nuclear explosions, Semipalatinsk Test Site (STS) and Novaya Zemlya Test Site), in the Sahara desert (France) and on Amchitka Island (USA) were chosen due to their appropriate relative location to the territory of the Northern Eurasia. Recently published data on peaceful nuclear explosions (PNEs) in the USSR (Sultanov et al, 1999) as well as previously and recently published data on nuclear underground tests at the Semipalatinsk Test Site (Bocharov et al, 1989; Adushkin et al, 1997; Belyashova, 1999), on Amchitka Island (Springer et al, 1971 and Springer et al, 1975) and in the Sahara desert (Duclaux et al, 1972) allowed the development of a database using well-characterized calibration events. Calibration events of the GT0 category were primarily used for the development of regional travel-time tables.

Data on Travel Times

Data resources were formed on the basis of seismic observations conducted during the time framework of 1965 - 1990 by the Geophysical Survey (GS) of the RAS and the Complex Seismological Expedition (CSE) of the Joint Institute of Physics of the Earth of the RAS. Values of arrival times for major regional seismic phases (Pn/P, Pg, Sn/S and Lg) were measured, analyzed and collected.

The total number of the GS's stations used for the purposes of seismic calibration is about 400. The total number of the CSE's stations used for the purposes of seismic calibration is about 200. Data of seismic observations of the RAS's institutions was added by the data of about 300 station in the Northern Eurasia providing data to the International Seismological Center.

Results

The regional travel-time curves were constructed using linear regression of the experimental travel time data using one or two linear regressions for the residual standard deviation minimization. Modeling errors were calculated as standard deviations of the experimental data from the estimated lines in a 2-degree moving window with a 50 % overlap. The basic equation and the parameters of the developed travel-time tables are presented in the Table 2. Modeling errors for the developed travel-time tables are presented in the Table 3. The newly developed regional travel-time tables differ substantially from the IASPEI-91 travel-time tables (see the Abstract). Figures 2, 3 and 4 represents the comparison of the Pn, Sn, Pg and Lg reduced travel-time curves for: (1) Central-East-European territory, West-Siberian platform, Siberian platform, (2) Ural folded region, Kazakh massif, Baikal rift zone, (3) Cenozoic folded regions, Altai and Sayan region, North-East territory and Chukot Peninsula and IASPEI-91. We grouped the aforementioned provinces taking into account the similarity of Pn and Sn reduced travel-time tables.

Tests on Relocation

We have located 21 historical underground nuclear explosions at the STS with published ground truth time of origins and locations (Bocharov et al, 1989) using the IASPEI-91 travel-time tables. Then, we relocated the aforementioned set of the explosions using the newly developed travel-time tables. We used the network of eight regional seismic stations included in the IMS (ZAL, MAK, NRI, GEYT, BRVK, ARU, AAK, TLY) or those stations, which are located not farther than 300 km from the IMS stations within geotectonically homogeneous regions. The aforementioned stations are located at the range of 6^{O} to 20^{O} from the underground nuclear explosions. The defining phases were: Pn, Sn, Pg and Lg. LocSat, provided by DTRA's Center for Monitoring Research (CMR), was used for the relocation tests.

The testing and validation metrics are as follows:

- 90% of events moved closer to the GT epicenters with an average improvement of 8.7 km and a median improvement of 7.0 km;
- 76% of events moved closer to the GT epicenters by 20% or more with an average improvement of 7.2 km and median improvement of 7.0 km;
- 10% of events moved away from GT epicenters with an average deterioration of 7.8 km and a median deterioration of 7.8 km;
- the same 10% of events moved away from GT epicenters by 20% or more;
- average mislocations by using the IASPEI-91 travel-time tables and the regional travel-time tables are 18.9 km and 8.2 km, respectively;
- median mislocations by using the IASPEI-91 travel-time tables and the regional travel-time tables are 14.9km and 7.9 km, respectively;
- 33% of GT epicenters are within the calculated 90% uncertainty ellipses by using the IASPEI-91 travel-time tables and 80% of GT epicenters are within the calculated 90% uncertainty ellipses by using the regional travel-time tables;
- average uncertainty ellipse area is 442 km^2 for the IASPEI-91 travel-time tables and 327 km^2 for the regional travel-time tables;
- median uncertainty ellipse area is 408 km^2 for the IASPEI-91 travel-time tables and 313 km^2 for the regional travel-time tables;
- average and median decrease of 90% uncertainty ellipse size is 115 km^2 and 103 km^2, respectively;
- average bias in origin time estimation is 1.1 sec with an associated standard deviation of 1.0 sec (median bias is 1.1 sec) for the IASPEI-91 travel-time tables and -0.5 sec with an associated standard deviation of 0.8 sec (median bias is -0.4 sec) for the regional travel-time tables.

CONCLUSIONS AND RECOMMENDATIONS

1. The regional travel-time tables for the different geotectonic provinces of the Northern Eurasia were newly developed and compared with the IASPEI-91 tables. The developed regional travel-time tables differ substantially from the IASPEI-91 travel-time tables.
2. Validation testing using ground truth data related to the underground nuclear explosions at the STS shows that estimates of event locations and time origins are significantly improved and location error ellipses are substantially reduced using the newly developed travel-time tables.
3. At the final stage of the project performance we are planning to complete the development of regional travel-time tables for the remaining geotectonic provinces of the Northern Eurasia, to clarify the previously developed travel-time tables taking into account still coming travel-time data from our subcontractors and to continue relocation tests using ground truth time of origins and locations for underground nuclear explosions at the territory of the USSR and DetSSSC's software developed at the CMR (Xioping Yang et al, 1998).

REFERENCES

Adushkin, V.V., V.A. An, V.M. Ovchinnikov and D.N. Krasnoshchekov, A jump of the Density on the Outer-Inner Core Boundary from the Observations of PkiKP Waves on the distance about 6 ^{O}, Transactions of the RAS, Vol. 354, No. 3,1997.

Belyashova, N.N. National Nuclear Center of Kazakhstan Republic, Table of Locations of Balapan Nuclear Explosions Newly Mapped by NNCKR, Calibration Workshop, 12-14 January 1999, Oslo, Norway.

Bocharov, V.S., S.A. Zelentsov and V.N. Mikhailov, Characteristics of 92 Underground Nuclear Explosions at the Semipalatinsk Test Site, Atomnaya Energiya, Vol. 87, No. 3, 1989.

Deep Structure of the USSR Territory. Moscow. Nauka Publishing House, 1991 (in Russian).

Duclaux, F., M.L. Michaud, Conditions Experimentals des Tirs Nucleaires Souterains Francais au Sahara, R. Acad. Sc., Paris, Vol. 270, Serie B, 189-192,1972.

Pavlenkova N.I., Crust and Upper Mantle Structure in Northern Eurasia from Seismic Data. Advances in Geophysics, Vol. 37, Academic Press, 1996.

Seismicity and Seismic Zoning of Northern Eurasia. Vol. 1. Moscow: IPE RAS,1993 (in Russian).

Seismicity and Seismic Zoning of Northern Eurasia. Vol. 2-3. Moscow: UIPE RAS,1995 (in Russian).

Springer, D.L. and R.L. Kinnaman, Seismic Source Summary for U.S. Underground Nuclear Explosions, 1961-1970. Bull. Seim. Soc. Am., Vol.61, 1073-1098, 1971, and Seismic Source Summary for U.S. Underground Nuclear Explosions, 1971-1973. Bull. Seim. Soc. Am., Vol.65, 343-349, 1975.

Sultanov, D.D., J.R. Murphy, and Kh.D. Rubinstein, A Seismic Source Summary for Soviet Peaceful Nuclear Explosions, Bull. Seim. Soc. Am., Vol.89, No.3, 1999.

Xioping Yang, Keith McLaughlin, Robert North, SSSCs for Regional Phases at IMS Stations in North America and Fennoscandia, Technical Report CMR-98/46.

Table 1. Regionalization of Northern Eurasia

Region No.	Region name	Polygon Vertices, Lat. (deg. N) - Long. (deg. E)			
I	Central-East-European territory	72-6 48-56	72-48 48-12	70-48 52-12	70-56 52-6
II	Cenozoic folded regions	48-12 40-90 32-72	48-62 40-78 32-42	46-62 38-78 36-42	46-90 38-72 36-12
III	Ural folded region	78-48 48-62	78-72 48-56	74-72 70-56	74-62 70-48
IV	West-Siberian platform	78-72 58-86 74-62	78-102 58-82 74-72	70-102 54-82	70-86 54-62
V	Kazakh massif	54-62	54-82	46-82	46-62
VI	Altai and Sayan region	58-82	58-104	46-104	46-82
VII	Siberian platform	78-102 54-138 58-104	78-132 54-114 58-86	64-132 60-114 70-86	64-138 60-104 70-102
VIII	Baikal rift zone	60-104	60-114	48-114	48-104
IX	Amur and Maritime territory	54-114	54-142	42-142	42-114
X	North East territory And Chukot Peninsula	76-132 60-156 64-132	76-168W 58-156 76-132	60-168W 58-138	60-168 64-138
XI	Kamchatka-Kuril- Sakhalin region	60-156 48-162 54-142	60-168 48-156 54-138	52-168 42-156 58-138	52-162 42-142 58-156

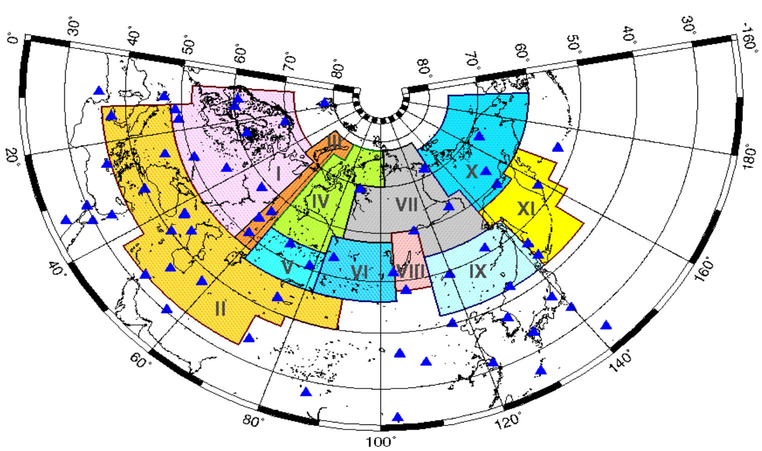

Figure 1. Regionalization of Northern Eurasia
I. Central-East-European territory II. Cenozoic folded regions III. Ural folded region IV. West-Siberian platform V. Kazakh massif VI. Altai and Sayan regions VII. Siberian platform VIII. Baikal rift zone IX. Amur and Maritime territory X. North East territory and Chukot Peninsula XI. Kamchatka-Kuril-Sakhalin region, ? - IMS stations

Table 2. Parameters of the Developed Travel-Time Curves (Depth = 0 km)
Basic Equation: $T\text{-}R/V_{red} = (A \pm s_A) - (B \pm s_B)$ ´R

Phase	Range, km	V_{red}, km/sec	A	s_A	B	s_B	N	r	SD, sec
I. Central-East-European territory									
Pn	250-1150	8.0	8.15	0.37	0.0044	0.0004	75	0.80	0.8
	1151-2500	8.0	14.63	0.39	0.0098	0.0002	288	0.93	1.5
Sn	250-2500	4.62	15.76	0.75	0.0058	0.0005	235	0.59	3.4
Pg	250-1300	6.0	0.64	0.67	0.0062	0.0006	75	0.75	1.6
Lg	250-2500	3.5	-2.25	1.28	0.0016	0.0009	167	0.13	5.0
II. Cenozoic folded regions									
Pn	200-1800	8.0	8.79	0.36	0.0033	0.0003	224	0.59	1.9
Sn	250-2000	4.62	12.12	1.23	-0.0020	0.0012	84	0.18	4.4
Pg	250-1200	6.0	1.25	1.19	0.0056	0.0016	57	0.43	2.4
Lg	200-2200	3.5	0.87	1.63	0.0045	0.0016	85	0.29	5.3
III. Ural folded region									
Pn	250-2000	8.0	8.23	0.40	0.0048	0.0004	59	0.87	1.2
Sn	250-2000	4.62	12.86	1.22	-0.0002	0.0011	53	0.03	3.3
Pg	250-1200	6.0	-0.60	1.06	0.0047	0.0014	35	0.50	1.8
Lg	200-2200	3.5	-2.08	1.21	0.0018	0.0012	38	0.24	3.1
IV. West-Siberian platform									
Pn	250-2300	8.0	8.84	0.54	0.0065	0.0004	89	0.90	1.7
Sn	300-2200	4.62	15.69	1.27	0.0036	0.0009	86	0.38	4.1
Pg	250-1200	6.0	-0.54	1.45	0.0052	0.0016	42	0.46	2.3
Lg	250-2200	3.5	-1.62	1.49	0.0034	0.0011	82	0.33	4.8
V. Kazakh massif									
Pn	250–777	8.0	8.11	0.39	0.0026	0.0006	57	0.51	1.0
	778-2200	8.0	10.71	0.68	0.0061	0.0004	74	0.87	1.3
Sn	250-2000	4.62	15.96	0.86	0.0037	0.0007	82	0.49	2.9
Pg	300-1200	6.0	0.28	1.28	0.0045	0.0016	28	0.49	1.9
Lg	250-2300	3.5	-2.24	1.17	0.0027	0.0010	86	0.28	4.2
VI. Altai and Sayan region									
Pn	250-1600	8.0	8.40	0.62	0.0010	0.0008	62	0.23	1.6
Sn	300-2200	4.62	13.25	1.60	-0.0007	0.0011	57	0.08	4.2
Pg	300-1200	6.0	-0.93	3.05	0.0026	0.0031	25	0.17	3.3
Lg	250-2200	3.5	-6.60	1.47	-0.0020	2.1013	99	0.21	4.2
VII. Siberian platform									
Pn	250-2300	8.0	9.83	0.39	0.0069	0.0002	206	0.90	1.4
Sn	600-2300	4.62	16.99	1.04	0.0067	0.0006	174	0.64	3.0
Pg	300-1300	6.0	-0.90	1.54	0.0055	0.0014	29	0.60	1.9
Lg	250-2500	3.5	-3.51	1.18	0.00002	0.0007	189	0.03	4.0
IX. Baikal rift zone									
Pn	400-2000	8.0	6.83	0.59	0.0032	0.0006	282	0.87	1.3
Sn	400-2000	4.62	12.36	1.04	0.0008	0.0007	178	0.61	3.3
Pg	400-1200	6.0	-0.89	1.32	0.0037	0.0017	121	0.53	1.8
Lg	400-2500	3.5	-6.41	0.59	-0.0020	0.0004	245	0.34	4.0
XI. North East territory and Chukot Peninsula									
Pn	350-2000	8.0	9.97	0.79	0.0044	0.0006	27	0.85	1.5
Sn	500-2200	4.62	6.62	2.48	-0.0050	0.0018	17	0.58	4.0
Pg	500-1200	6.0	1.56	2.31	0.0051	0.0023	7	0.69	2.0
Lg	400-2500	3.5	-0.99	2.42	-0.0013	0.0014	17	0.23	4.0

Note: **T - travel time, sec;**
R - epicentral distance, km;
V_{red} - reduction velocity, km/sec;
N - data set;
r - correlation coefficient;
SD - residual standard deviation, sec.

Table 3. Modeling Errors for the Eurasian Geotectonic Provinces

Dis-tance, deg.	I. Central-East-European territory				II. Cenozoic folded regions				III. Ural folded region				IV. West –Siberian platform			
	Modeling Error, sec				Modeling Error, sec				Modeling Error, sec				Modeling Error, sec			
	Pn	Pg	Sn	Lg	Pn	Pg	Sn	Lg	Pn	Pg	Sn	Lg	Pn	Pg	Sn	Lg
3	0.5	0.9	3.8	4.5	0.4	1.9	3.8	4.6	0.8	1.9	3.7	3.2	1.8	2.1	1.8	3.9
4	0.4	1.0	3.9	4.7	1.3	2.9	3.9	4.3	0.6	2.0	2.2	3.5	1.8	2.2	1.2	3.7
5	0.9	1.7	2.9	6.7	1.2	3.0	2.9	4.8	1.0	1.9	2.2	3.4	1.7	3.2	4.9	4.7
6	0.9	1.6	2.6	7.0	1.2	1.9	2.6	3.9	1.4	1.8	2.6	3.4	1.7	3.3	7.0	1.8
7	0.6	1.3	2.9	5.7	1.2	1.7	2.9	3.9	1.5	2.9	2.9	2.9	1.7	2.6	3.7	4.4
8	0.7	1.0	3.4	2.6	1.8	2.3	3.4	5.4	0.6	2.0	4.7	3.0	1.7	2.5	4.4	3.7
9	0.8	1.4	3.3	3.8	2.1	3.2	3.3	6.6	1.1	1.2	4.3	4.6	1.4	2.2	4.0	4.1
10	1.2	1.7	3.9	4.4	1.8	3.0	3.9	5.8	1.6		2.4	6.9	1.3	2.0	2.9	5.0
11	1.2	1.7	3.4	5.1	2.1		3.4	7.3	1.6		2.7	3.9	1.5		3.4	5.9
12	1.4		2.9	5.7	2.2		2.9	9.2	1.5		4.7	3.6	1.5		4.1	4.6
13	1.6		3.5	4.5	1.9		3.5	6.0	1.4		4.4	4.0	1.4		5.1	4.5
14	1.0		3.8	4.7	2.3		3.8	4.3	1.4		4.3	4.3	2.2		5.2	7.5
15	1.3		3.7	5.5	2.6		3.7	5.5	1.4		3.8	5.5	2.8		3.5	6.5
16	1.5		3.0	5.8	2.4		3.0	5.1	1.1		2.3	5.1	2.1		3.8	4.6
17	1.3		3.0	6.3	2.4		3.0	6.3	1.0		3.0	6.3	1.6		5.3	4.4
18	1.2		3.5	7.1			3.5	7.1	0.5		3.5		1.8		6.8	4.1
19	1.5		2.7	7.1			2.7	7.1			2.7		1.0		2.9	7.0
20	1.5		3.2	3.7			3.2	3.7			3.2		0.9			

Table 3 (continued)

Dis-tance deg.	VI. Altai and Sayan region				VII. Siberian platform				VIII. Baikal rift zone				X. North
	Modeling Error, sec				Modeling Error, sec				Modeling Error, sec				Mod
	Pn	**Pg**	**Sn**	**Lg**	**Pn**	**Pg**	**Sn**	**Lg**	**Pn**	**Pg**	**Sn**	**Lg**	**Pn**
3	1.0	2.0	2.7	3.5	2.0	3.0	3.0	4.5	1.3	1.2	1.9	3.6	0.5
4	1.0	2.5	2.9	3.1	2.0	2.5	2.5	4.2	1.2	2.0	1.8	2.9	1.4
5	1.1	3.6	3.3	3.2	0.5	2.2	3.9	4.0	1.2	1.9	2.2	3.1	1.4
6	0.9	4.5	3.7	3.0	1.2	2.4	2.3	3.7	1.2	1.6	2.1	2.9	1.5
7	1.5	4.6	3.0	3.5	1.4	2.3	3.0	3.8	1.2	1.2	2.6	3.0	1.0
8	1.8	3.5	2.8	3.4	1.6	2.3	4.0	3.6	1.1	1.5	3.2	3.3	0.8
9	1.7	3.1	3.4	4.0	1.5	2.0	4.1	5.2	1.6	2.1	3.2	3.9	1.0
10	1.9	3.1	3.7	3.6	1.3	1.8	3.1	5.7	1.6		3.6	4.4	1.7
11	2.3		5.2	5.0	0.9	1.6	2.8	3.9	1.3		3.6	4.5	1.1
12	3.1		5.7	6.5	1.1		2.9	3.1	1.4		3.9	4.1	1.1
13	2.4		4.4	5.3	1.7		3.3	3.9	1.3		4.9	3.4	1.4
14	1.0		4.7	4.1	1.9		4.3	4.1	1.1		5.1	3.5	1.5
15	0.8		5.8	3.5	1.7		4.3	3.7	2.1		5.3	4.3	1.6
16			6.1	4.6	1.6		3.2	4.0	2.6		5.0	4.4	1.4
17			4.6	5.2	1.4		2.9	3.9	2.1			4.2	2.3
18			4.7	6.2	1.4		2.9	3.4					
19			4.0	6.7	1.1		2.2	3.3					
20					1.1		2.1	3.9					

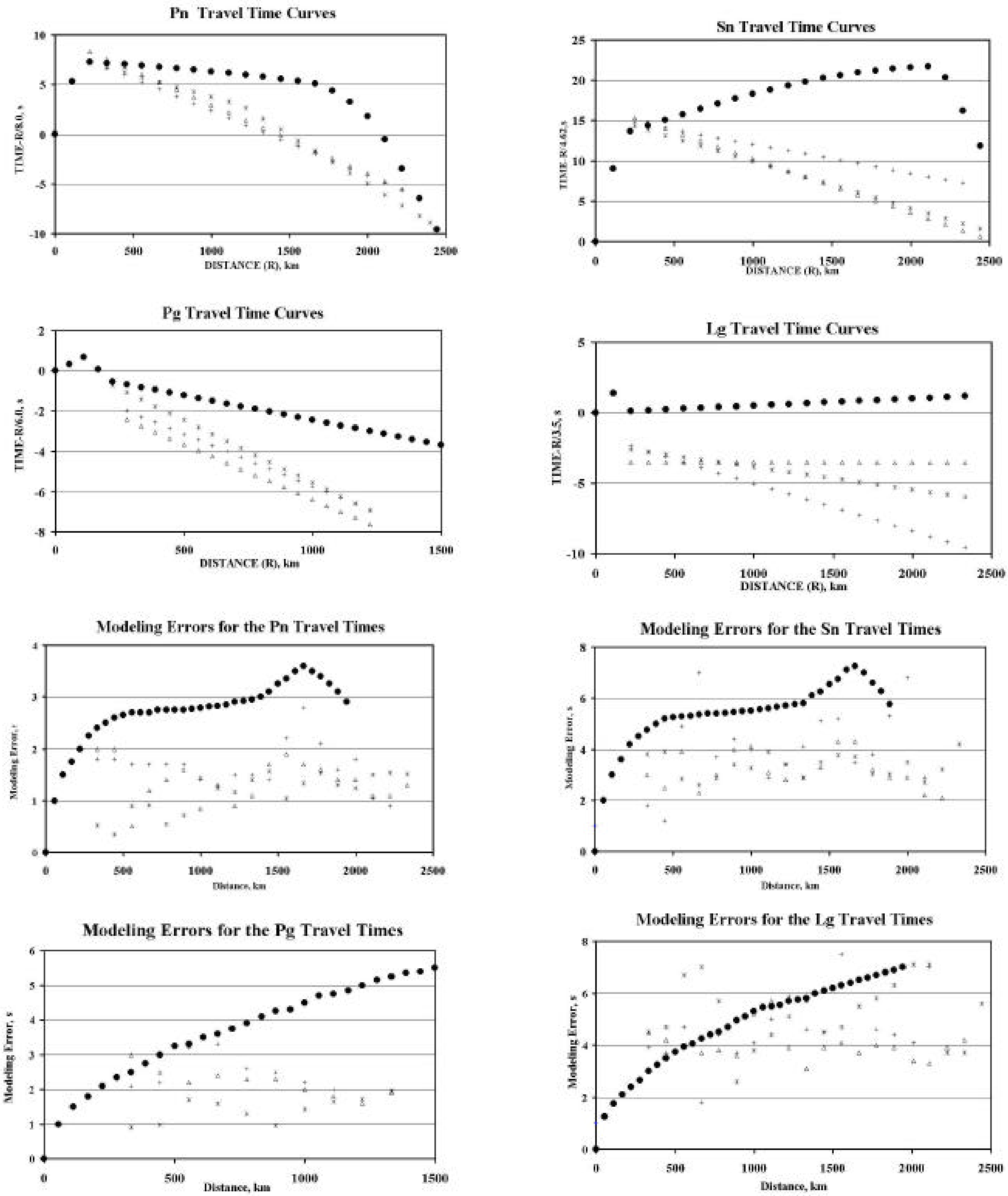

Figure 2. Comparison of Pn, Sn, Pg and Lg reduced travel-time curves and modeling errors for Central-East-European territory (+), West-Siberian platform (*), Siberian platform (?) and IASPEI-91 (?).

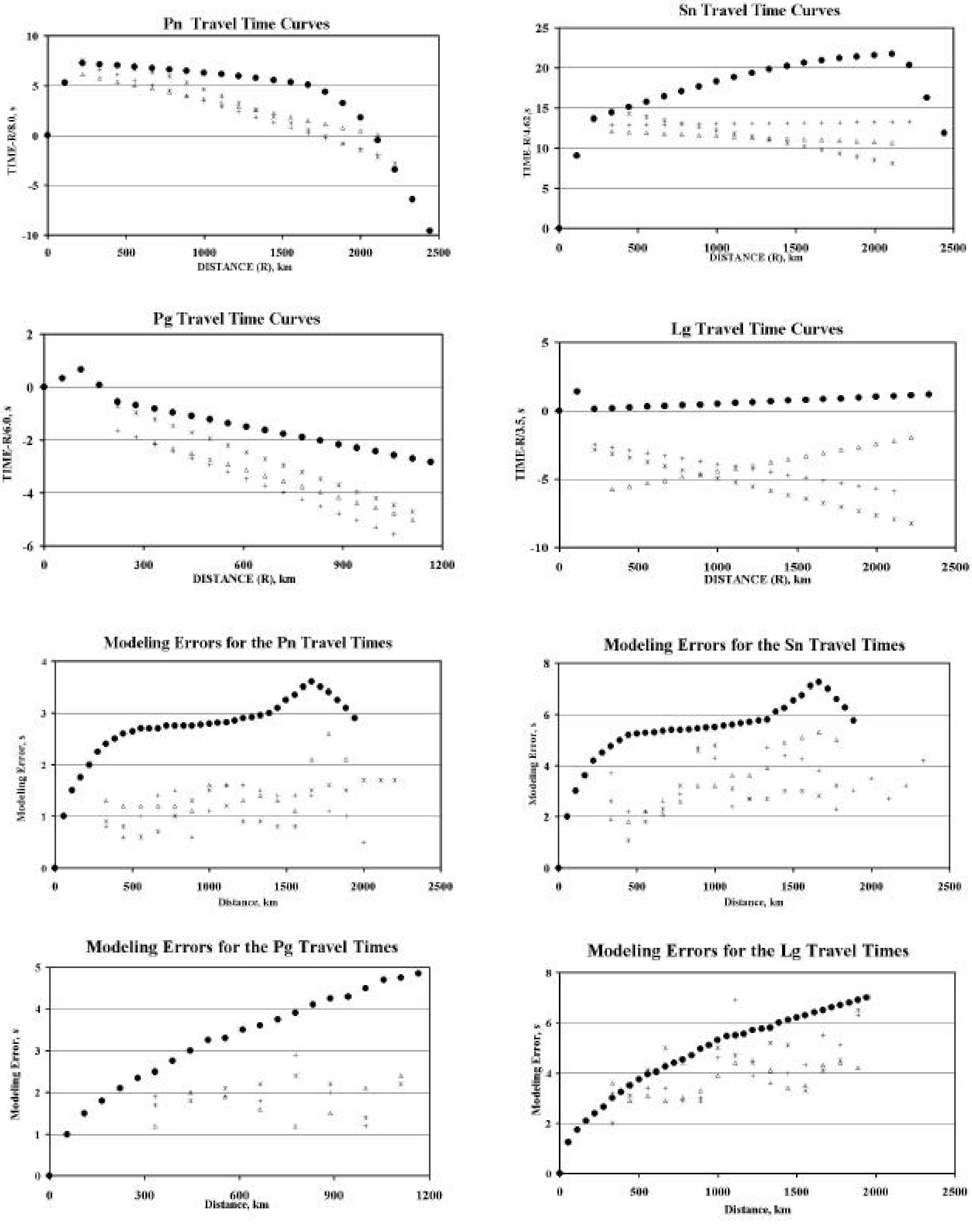

Figure 3. Comparison of Pn, Sn, Pg and Lg reduced travel-time curves and modeling errors for Ural folded region (+), Kazakh massif (*), Baikal rift zone (?) and IASPEI-91 (?).

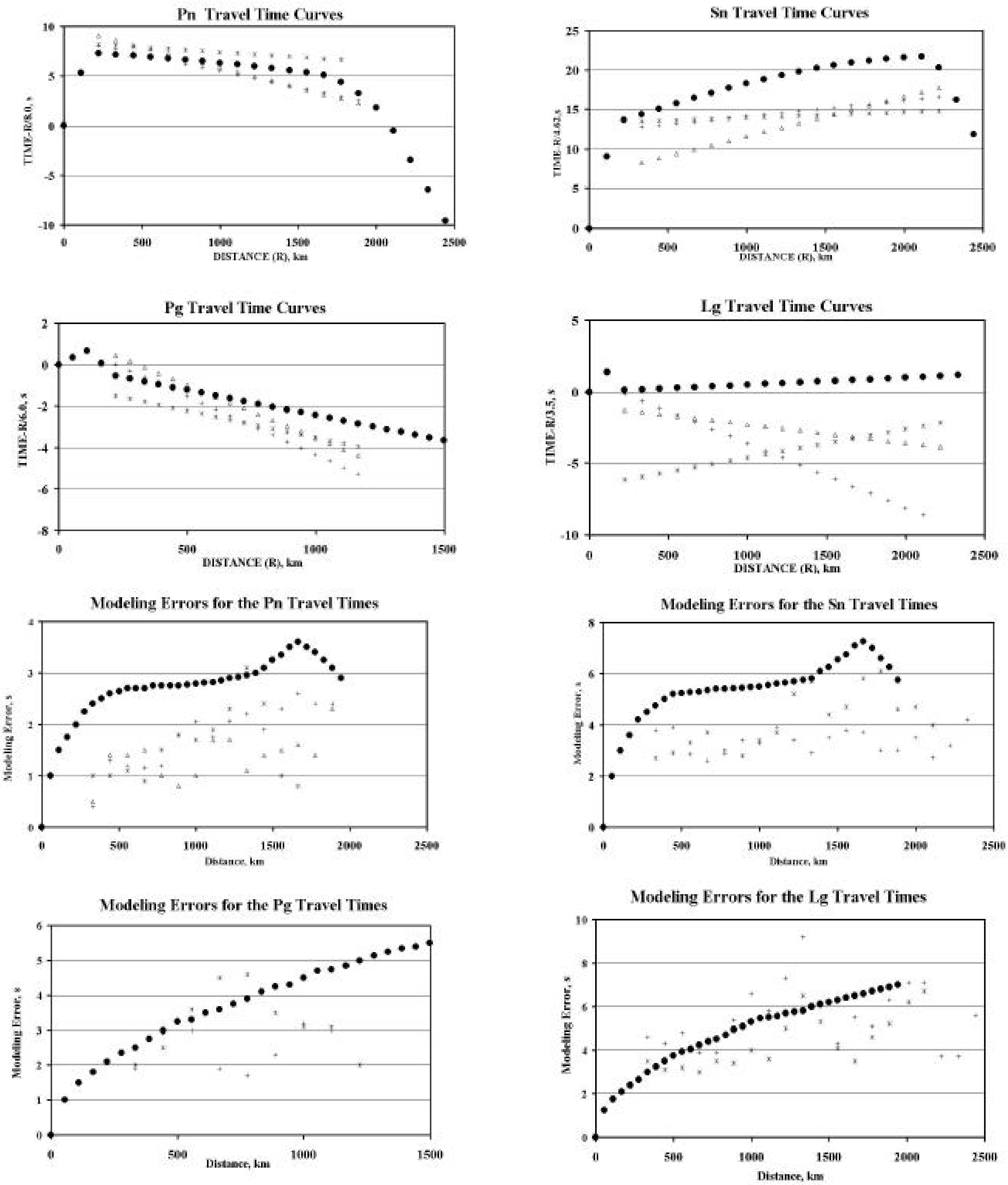

Figure 4. Comparison of Pn, Sn, Pg and Lg reduced travel-time curves and modeling errors for Cenozoic folded regions (+), Altai and Sayan regions (*), North-East territory and Chukot Peninsula (?) and IASPEI-91 (?).